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Alternating Days of Intermittent Hypoxic Exposure (IHE) on Physical and Cognitive Performance

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14. ABSTRACT
Rapid deployments do not allow our airmen to slowly progress to high altitudes, so predeployment strategies for the optimal use of hypoxic tents need to be developed. The primary objective of this study was to determine if alternating days of intermittent normobaric hypoxic exposures (IHE) for previously unacclimatized, sea-level residents (SLR) would work as a training strategy to minimize physical and cognitive impairments, and possibly reduce acute mountain sickness (AMS) incidence in our battlefield airmen during deployment. A secondary objective was to compare the physical and cognitive performance results between normobaric hypoxic and hypobaric hypoxic conditions. We conducted a crossover style, randomized study to assess the efficacy of IHE on physical and cognitive performance decrements. Baseline physical tests were conducted at SL, normobaric hypoxic (NH), and hypobaric hypoxic (HH) environments. Subjects were randomly assigned to either five consecutive (C-IHE) or five alternating (A-IHE) days of IHE. All tests were repeated post-IHE exposure. Following a four-week washout interval, all subjects repeated the process again under the opposite IHE exposure schedule. Intra-subject differences between training regimens (C-IHE vs. A-IHE) and the three environments (SL vs. NH vs. HH) were analyzed. Seven well-conditioned (average VO_2 max = 57 $mL^{-1} \cdot Kg^{-1} \cdot min$) male subjects (30.4 ± 8.7 yrs) completed the study. Significant physiological differences in VO_2 max ($p<0.001$) and oxygen saturation ($p<0.01$) between SL and NH or HH were observed. There were no significant differences in the HH environment for any performance variables following C-IHE and A-IHE training regimens. A-IHE produces the same altitude adaptations as C-IHE, which may allow our battlefield airmen to better prepare themselves for moderate altitude (MA) deployments. Our recommendation is that further research be conducted in this area with increased number of hypoxic training sessions of longer durations.

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List of Symbols, Abbreviations, and Acronyms

711 HPW	711th Human Performance Wing
AFRL	Air Force Research Laboratory
AFSOC	Air Force Special Operations Command
A-IHE	Alternating Intermittent Normobaric Hypoxic Exposures
AMS	Acute Mountain Sickness
ANOVA	Analysis of Variance
BAT	Battlefield Airman Test
Bpm	Beats per Minute
CAT	Colorado Altitude Tent
C-IHE	Consecutive Intermittent Normobaric Hypoxic Exposures
Cm	Centimeters
DEXA	Dual Energy X-ray Analysis
EPOC	Excessive post-exercise oxygen consumption
ESQ	Environmental Symptoms Questionnaire
GE	General Electric
HH	Hypobaric Hypoxia
HR	Heart Rate
IHE	Intermittent Normobaric Hypoxic Exposures
Kg	Kilograms
$L \cdot min^{-1}$	Liters per minute
LHTH	Live high-train high
LHTL	Live high-train low
LLS	Lake Louise Acute Mountain Sickness Scoring System
LLTH	Live low-train high
LLTL	Live low-train low
m	Meters
MA	Moderate altitude
microL	Microliters
min	Minute
mg	Milligrams
ml	Milliliters
$mL \cdot kg^{-1} \cdot min^{-1}$	Milliliters per kilogram per minute
$mmol \cdot L^{-1}$	Millimoles per liter
mph	Miles per hour
n	Number of subjects
NH	Normobaric Hypoxic
PT	Physical Training

RCV	Red blood cell volume
s or secs	Seconds
SaO_2	% Arterial Oxygen Saturation
SCWT	Stroop Colored Word Test
SD/Std Dev	Standard Deviation
SLR	Sea-level Resident
STS	Special Tactics Squadron
STTS	Special Tactics Training Squadron
tHb	Total hemoglobin mass
TTE	Time-to-exhaustion
U.S.	United States
USAF	United States Air Force
VO_2max	Maximal Oxygen Uptake
VT	Ventilatory Threshold

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Executive Summary

Purpose:

The primary objective of this study was to determine if alternating days of intermittent normobaric hypoxic exposures (IHE) for previously unacclimatized, sea-level residents (SLR) would work as a training strategy to minimize physical and cognitive impairments, and possibly reduce acute mountain sickness (AMS) incidence in battlefield airmen during deployment. A secondary objective was to compare the physical and cognitive performance results between normobaric hypoxic and hypobaric hypoxic conditions.

Methods:

We conducted a crossover style, randomized study to assess the efficacy of IHE on physical and cognitive performance decrements. Baseline physical tests were conducted at sea-level (SL), and in normobaric hypoxic (NH) and hypobaric hypoxic (HH) environments. Subjects were randomly assigned to either five consecutive (C-IHE) or five alternating (A-IHE) days of IHE. All tests were repeated post-IHE exposure. Following a four-week washout interval, all subjects repeated the process again under the opposite IHE exposure schedule. Intra-subject differences between training regimens (C-IHE vs. A-IHE) and the three environments (SL vs. NH vs. HH) were analyzed.

Results and Conclusions:

Seven well-conditioned (average VO_2 max = 57 $mL^{-1} \cdot Kg^{-1} \cdot min$) male subjects (30.4 ± 8.7 yrs) completed the study. Significant physiological differences in VO_2 max ($p<0.001$) and oxygen saturation ($p<0.01$) between SL and NH or HH were observed. There were no significant differences in the HH environment for any performance variables following C-IHE and A-IHE training regimens. A-IHE produces the same altitude adaptations as C-IHE, which may allow battlefield airmen to better prepare themselves for moderate altitude (MA) deployments. Our recommendation is that further research be conducted in this area with an increased number of hypoxic training sessions of longer durations.

INTRODUCTION

Objective

The primary objective of this study was to determine if alternating days of intermittent normobaric hypoxic exposures (IHE) for a previously unacclimatized, sea-level resident (SLR) would work as a training strategy to minimize physical and cognitive impairments, and possibly reduce acute mountain sickness (AMS) incidence in battlefield airmen during deployment. A secondary objective was to compare the physical and cognitive performance results between normobaric hypoxic and hypobaric hypoxic conditions.

Background

Rapid deployment of unacclimatized airmen to high altitudes (i.e., > 4,000m) can compromise mission success by producing debilitating effects on fighting capabilities and force health. Typically, there is a 70% impairment in prolonged physical performance and a 20% decrement in cognitive performance within the first few days of exposure to high altitude for the unacclimatized individual (Muza, 2007, Fulco et al., 1994). This decrease in exercise performance is linked to the fall in alveolar oxygen tension and resulting loss of oxygen saturation (SaO_2) in the red blood cells (Drust & Waterhouse, 2010). In addition, some deployed airmen deployed will develop acute mountain sickness (AMS), a state characterized by symptoms such as headache, nausea, vomiting, fatigue, dizziness and insomnia (Muza et al., 2006, Roach et al., 1993). The incidence and severity of these impairments are increased with physical activities like rucking or climbing (Fulco et al., 1994).

Altitude acclimatization, or adaptation, begins within several hours of altitude exposure and consists of beneficial physiological adjustments that develop in a time-dependent manner over a period of days to weeks. Altitude acclimatization improves physical and cognitive performances, and lowers the incidence of AMS (Fulco et al., 1994). Various levels of altitude acclimatization are accomplished by progressing slowly to the desired altitude with days of rest, known as staging, at intermediate altitudes along the way or by acclimating at simulated altitudes with artificial high-altitude environments known as normobaric hypoxic rooms or tents (Rankovic & Radovanovic, 2005). These rooms create a hypoxic condition by decreasing the oxygen partial pressures within the enclosed room. Rapid deployments do not allow our airmen to slowly progress to high altitudes so pre-deployment strategies for the optimal use of hypoxic tents need to be developed.

Elite athletes have been using altitude training for many years in an effort to improve sea level performance (Rankovic & Radovanovic, 2005). The primary goal of any altitude-training program is to improve long term oxygen transport and/or oxygen utilization by limiting oxygen availability during these intermittent hypoxic conditions. Additionally, high altitude training benefits may include increased muscle buffer capacity and exercise efficiency (Gore et al., 2001, Katayama et al., 2003, Katayama et al., 2004), increased serum erythropoietin (EPO) (Gore et al., 2006; Heinicke et al., 2005), increased red blood cell volume (RCV), total hemoglobin mass (tHb) (Heinicke et al., 2005), and anaerobic power (Hendriksen & Meeuwsen, 2003). The four major variations of altitude training consist of live high-train high (LHTH), live high-train low (LHTL), live low-train high (LLTH) and live low-train low (LLTL) with intermittent normobaric hypoxic exposures (IHE) (Millet, Roels, Schmitt, Woorons, & Richalet, 2010). Athletes or airmen must be located close to a moderate altitude to perform any of the first three programs, while the fourth (IHE) can be accomplished at any sea level to moderate altitude location with the use of a artificial high-altitude environment with intermittent normobaric hypoxic exposures. Our experimental design was set-up to take live low-train low (LLTL) subjects to simulated LHTL conditions.

Current recommended procedures for using hypoxic tents for intermittent normobaric hypoxic exposures (IHE) are five consecutive days at 4,000 m (13,200 ft) for 1.5 hours or more during the week prior to high altitude deployments (Muza, Beidleman, & Fulco, 2010, Muza, 2007). This schedule is very hard to accomplish with the additional demands placed on airmen during the week prior to deployment. Alternating exposure days would lessen the time demands during a high ops tempo on our deploying airmen while still providing the necessary high altitude adaptations.

METHODS

Participants

Eight male United States Air Force members, ages 24-44, signed institutionally-approved informed consent documents and were enrolled into the study upon receiving medical approval. One subject dropped out prior to starting any tests and is not included in the data analysis. One other subject was unable to complete the entire protocol for reasons unrelated to the protocol itself. His partial data is included in the data analysis.

Facilities

All training and testing was conducted in the Air Force Research Laboratory Human Performance Laboratory or Hypobaric Chamber "E" (Figure 1) at Brooks City-Base, Texas. IHE sessions were conducted in a Colorado Altitude Training (CAT) Exercise Room (Figure 2.). The CAT is a 10' by 10' by 8' structure that utilizes a high-flow hypoxic air delivery unit. The multiple air units draw in ambient room temperature air and seperates the oxygen molecules from the nitrogen molecules. The oxygen molecules are released back into the ambient air while the nitrogen is allowed to freely flow into the CAT creating an oxygen-reduced environment. The percent oxygen was decreased to 12.5% to simulate 14,300 feet. This system is capable of duplicating oxygen levels found at altitudes of 15,000 ft (4,572 m).

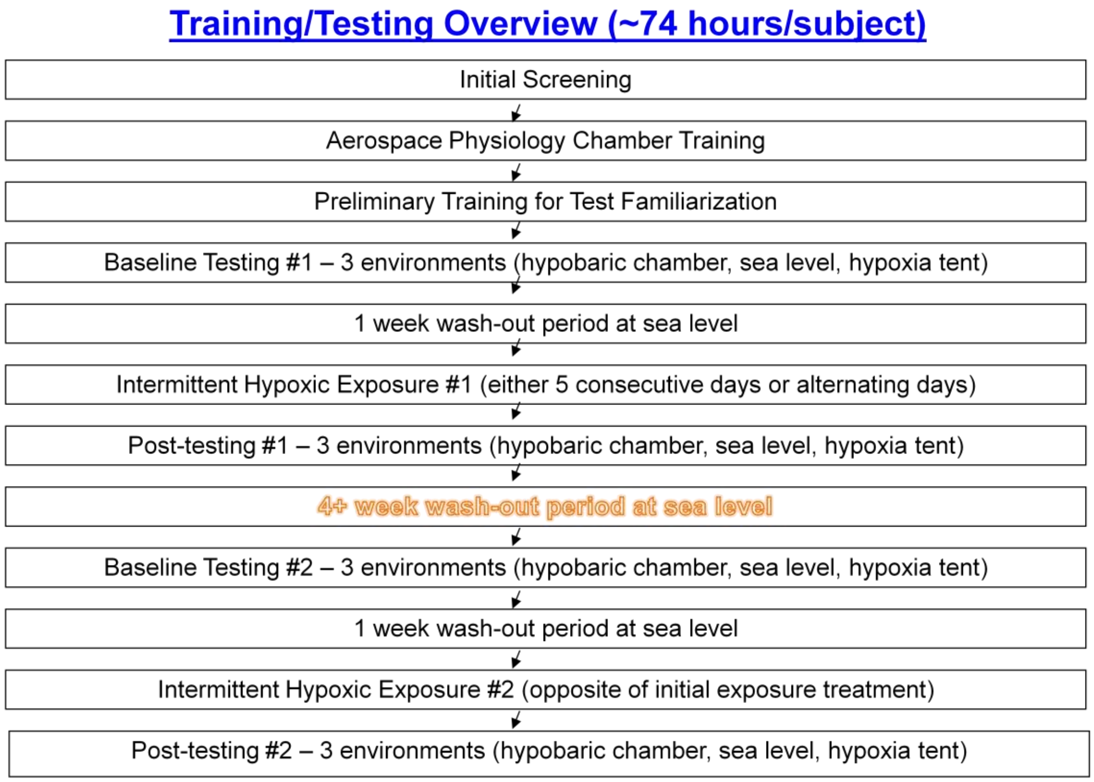
Figure 1. E-Chamber

Figure 2. Colorado Altitude Tent (CAT)

Experimental Design

Each subject was medically and physically screened and completed a USAF Aerospace Physiology course that included an exposure to 25,000 ft in a hypobaric chamber prior to being enrolled in the study. Subjects underwent one day of training and test familiarization on the various test equipment. Subjects then underwent initial pretesting in each of three environments: 14,300 ft in the hypobaric chamber, sea level, and 14,300 ft in the hypoxic tent. All subjects were exposed to testing conditions were done in the same order. The subjects were then randomized into two groups for their IHE treatment. One group completed five consecutive days of IHE (C-IHE) while the other group completed their five exposures on alternating (A-IHE) days. All IHE treatments were followed by post-testing in the same three environments in the same order as pre-testing. Subjects were not allowed to consume > 100mg caffeine on each test day. A washout period of four or more weeks followed to allow the subjects to reacclimatize to the sea-level environment. The subjects were then put through the entire pretesting, IHE, and post-testing procedures again under the opposite exposure schedule. Table 1 provides a summary of the testing. It took each subject six to eight months to complete the study.

Table 1. Testing Flow Chart with Time Requirements



Screening Procedures

All volunteers had to pass a physical performance screening before being enlisted as a subject. The purpose of this screening was to insure that our subject pool was a reasonable cohort to the highly fit Air Force special operators who will be using the CAT. The following screening tests and passing standards were used:

- *Body Composition*. Measured by dual energy X-ray absorptiometry (DEXA) (Lunar Prodigy, GE, Waukesha, WI, USA). Subjects were accepted if their body fat was less than 20%.
- *Push-ups.* Subjects had two minutes to complete a minimum of 60 push-ups.
- *Sit-ups.* Subjects had two minutes to complete a minimum of 75 sit-ups.
- *Vertical Jump.* A Vertec (Questec Corp., Northridge, CA) vertical measuring device was used to measure vertical jump height. Subjects needed to have a vertical jump greater than 18 inches.
- *Grip Strength Test.* A handgrip dynamometer (Lafayette Instruments, Lafayette, IN) was used to calculate the subject's grip strength. Grip strength had to be no less than 50kg.
- *1.5 mile run.* Subjects had to complete a 1.5 mile run in less than 11:30 minutes.

Test Procedures

Cardiorespiratory Endurance. The maximal oxygen uptake (VO_2 max)/running-economy protocol (Table 2) was conducted on a Woodway DESMO treadmill (Woodway USA, Waukesha, WI). Each subject was fitted with a harness and a facemask to collect expired air for the Parvo Medics' TrueOne 2400 metabolic measurement system (Consentius Technologies, Sandy, UT). Subjects wore a Polar heart rate monitor transmitter (Polar Electro, Inc., New York, NY) around the chest to measure heart rate (HR) response throughout the warm-up, test, and recovery phases of the protocols. After a one-minute rest period to verify transmitter communication, subjects performed a two-minute walk at a 2.0 mph. Upon completion of the two-minute walk, treadmill speed increased to 7.0 mph at 0% grade. This speed and grade was maintained for three minutes to test for 7.0 mph running economy. Following that stage, the 7.0 mph speed was maintained while the grade increased by 2% increments every minute until it reached a 10% grade, after which it increased by 1% each minute until it reached a 15% grade or until subjects reached volitional fatigue. If subjects did not reach volitional fatigue at the maximum treadmill grade of 15 %, the treadmill speed increased by 0.5 mph every minute until the subject reached volitional fatigue. Once volitional fatigue was reached, the treadmill's speed slowed to a 2.0 mph pace at 0% grade to induce active recovery until their heart rate dropped below 120 bpm. At the one-minute recovery stage, the subject received a finger stick for blood lactate collection (10 microL). These one-minute post-test lactates were analyzed using the Lactate Pro system (Arkray, Inc., Kyoto, Japan).

Table 2. Max VO_2/Running Economy Treadmill Protocol

Test Time (min)	Stage Time (min)	Speed (mph)	Grade (%)	Position
0-1	2:00	0	0	Rest
2-3	2:00	2.0	0	Walking
4-5	3:00	7.0	0	Running
6	1:00	7.0	2	Running
7	1:00	7.0	4	Running
8	1:00	7.0	6	Running
9	1:00	7.0	8	Running
10	1:00	7.0	10	Running
11	1:00	7.0	11	Running
12	1:00	7.0	12	Running
13	1:00	7.0	13	Running
14	1:00	7.0	14	Running
End of Test	Until HR <120	2.0	0	Active Recovery

Battlefield Airman Test. The Battlefield Airman Test (BAT) is an anaerobic endurance test of loaded running, designed by the investigators specifically for the combat controller population using the Woodway Force 2.0 human powered treadmill. Subjects were fitted with a Polar heart-rate monitor transmitter that monitored HR throughout the warm-up, test, and recovery phases. First, the subjects performed a two-minute warm-up on a Woodway Desmo treadmill striving to achieve a heart rate of 130-140 bpm. A Woodway waist belt was donned following the warm-up and attached to a force transducer on the rear post of the force treadmill. The treadmill was preprogrammed with five pounds of resistance internally loaded to the treadmill belt to provide extra load and to help alleviate any balance issues. Subjects started to jog and were then given five seconds to achieve a self-selected speed above 7.0 miles per hour. The test continued until the subject could no longer maintain a speed greater than 7.0 mph. Subjects were given one warning to increase their speed if they dropped under 7.0 mph and the test was terminated if they could not increase their speed or when their speed dropped below 7.0 mph for the second time. At one minute of recovery, the subject received a finger stick for blood lactate collection. These one-minute post-test lactates were analyzed using the Lactate Pro system (Arkray, Inc., Kyoto, Japan).

Reaction Time. Eye-hand reaction speeds were measured on the Makoto Sports Arena (Makoto USA, Centennial, CO) in reactive and proactive modes (Figure 3). A one minute rest was given between tests. Each test was performed twice and the better of the two scores was recorded. In the proactive test, the targets on a single tower remained activated until hit by the subject. The results of the proactive test were the average time to hit each target. In the reactive test, targets on a single tower only remained active for 0.74 seconds. If the subject did not hit the target in the allotted time, then the occurrence was recorded as a miss. The results of this test were the percentage of targets hit.

Figure 3. The Makoto Interactive Sports Arena™

The Stroop Colored Word Test (SCWT). The Stroop Colored Word Test (SCWT) was administered to test cognitive performance. The SCWT consisted of three pages (Figure 4). Each page had 40 items presented in 5 columns of 8 lines each. The first page had the words "BLUE," "GREEN," "YELLOW," "RED," and "PINK" arranged randomly printed in black ink on white paper with a restriction that the same color name is not be repeated next to itself. Each of the five words was presented eight times. This page provided the baseline time it took in seconds to name all 40 words. The second page also consisted of 40 items, all written as

"00000" printed in blue, green, yellow, red, or pink ink. The five colors also appear in a random sequence and were repeated eight times with no color appearing in successive items. This page yielded the color score that was the time it took to name the colors of all 40 items. The third page consisted of the words printed on the first page, but printed in the colors on the second page. The first two pages were blended, item by item. The first word on page 1 was printed in the color of the first item on page 2 to produce the colored word on page 3. No word matched the color it was printed in. This page was used to produce the color-word score. This score was based on the time it took in seconds to name the color when printed in a contrasting word (interference score).

BLUE	GREEN	BLUE	YELLOW	GREEN
YELLOW	BLUE	RED	GREEN	RED
PINK	RED	GREEN	RED	YELLOW
PINK	GREEN	PINK	YELLOW	RED
GREEN	BLUE	PINK	BLUE	YELLOW
PINK	RED	BLUE	RED	GREEN
BLUE	YELLOW	PINK	YELLOW	PINK
YELLOW	RED	BLUE	PINK	GREEN

Page 1

000000	000000	000000	000000	000000
000000	000000	000000	000000	000000
000000	000000	000000	000000	000000
000000	000000	000000	000000	000000
000000	000000	000000	000000	000000
000000	000000	000000	000000	000000
000000	000000	000000	000000	000000
000000	000000	000000	000000	000000

Page 2

BLUE	GREEN	BLUE	YELLOW	GREEN
YELLOW	BLUE	RED	GREEN	RED
PINK	RED	GREEN	RED	YELLOW
PINK	GREEN	PINK	YELLOW	RED
GREEN	BLUE	PINK	BLUE	YELLOW
PINK	RED	BLUE	RED	GREEN
BLUE	YELLOW	PINK	YELLOW	PINK
YELLOW	RED	BLUE	PINK	GREEN

Page 3

Figure 4. Stroop Colored Word Test

Physiological Assessment.

Acute Mountain Sickness. The incidence and severity of AMS was determined from information gathered using the Environmental Symptoms Questionnaire (ESQ) and the Lake Louise AMS Scoring System (LLS). The scores of the ESQ and LLS were compared to determine how well they correlate to each other. Each questionnaire was completed during all pre/post tests.

The ESQ is a self-reported, 68-question inventory used to document symptoms induced by altitude and other stressful environments (Sampson et al., 1983). A weighted average of scores from nine symptoms (e.g., headache, lightheaded, dizzy, etc.) designated "AMS-C" was calculated. AMS-C scores greater than 0.7 are defined as indicating the presence of AMS. The LLS consisted of a six question self-reported assessment of AMS symptoms (Roach et al., 1993). LLS scores that included headache and ≥ 3 points are diagnostic of AMS.

Hemoglobin Saturation (SaO_2). After completion of each test and the questionnaires, subjects' SaO_2 was measured with a finger pulse oximeter. The SaO_2 level was matched in real time to the AMS assessments. This was a non-invasive simple test where the device slipped on one finger and blood oxygen saturation was measured.

Statistical Analyses

For each performance, physiologic, and cognitive outcome measured, a separate repeated measures analysis of variance (ANOVA) was performed with three within-subject factors: training regiment (C-IHE and A-IHE); time (pre and post training regimen); and the three testing conditions (base level, normobaric hypoxic, and hypobaric hypoxic). Post-hoc comparisons to test whether pre-to-post changes differ between training regimens and testing conditions was accomplished using paired t-tests. An alpha value of $p<0.05$ was used in all comparisons to indicate statistical significance.

RESULTS

Table 3 summarizes the means and standard deviations for age, height, weight, and body composition for our seven male subjects. Ages ranged from 22 to 44 years. Height and weight ranged from 1.68 to 1.87 cm and 70.5 to 83.8 kg respectively. Percent body fat ranged from 6% to 26.7%.

Table 3. Subject Demographics

	Age (years)	**Weight (Kg)**	**Height (cm)**	**% Body Fat**
Mean	30.4	78.2	178.3	16.4
Std Dev	8.7	4.5	6.2	6.8
Range	22-44	70.5-83.8	168-187	6.0-26.7

The results of the VO_2 max testing are shown in Table 4. The results are shown for each treatment of C-IHE or A-IHE days. There were no differences between the and post-tests at any of the three environments (chamber, ground, or tent). There were also no differences between the types of treatment the subjects received (alternating or consecutive). There were significant differences in max VO_2, test time, and maximal heart rate between testing environments as shown in Figures 5, 6 and 7.

Table 4. Aerobic Max VO_2 Test Results

		Chamber Pretest	Chamber Posttest	Ground Pretest	Ground Posttest	Tent Pretest	Tent Posttest
Alternating Days	**Max VO_2 ± Std Dev**	33.8 ± 5.2	35.9 ± 4.7	58.8 ± 6.2	57.3 ± 5.1	37.1 ± 3.7	37.2 ± 4.5
	Max HR ± Std Dev	172.9 ± 8.2	174.1 ± 9.5	185.1 ± 8.2	188.5 ± 11.3	172.9 ± 5.7	174.8 ± 8.6
	Test Time ± Std Dev	523 ± 59.6	542.1 ± 60.3	729.1 ± 75.2	718.3 ± 51.9	540.8 ± 40.2	529.3 ± 75.4

Consecutive Days	**Max VO_2 ± Std Dev**	35.8 ± 3.8	36.6 ± 6.7	55.9 ± 6.0	57.7 ± 5.4	36.5 ± 6.1	36.9 ± 6.2
	Max HR ± Std Dev	174 ± 13.3	171.5 ± 9.4	182.6 ± 10.6	184.9 ± 10.9	172.9 ± 10.4	170.6 ± 10.6
	Test Time ± Std Dev	524.5 ± 59.6	568.0 ± 44.2	695.5 ± 76.8	707.3 ± 90.4	548.8 ± 39.5	517.1 ± 120.7

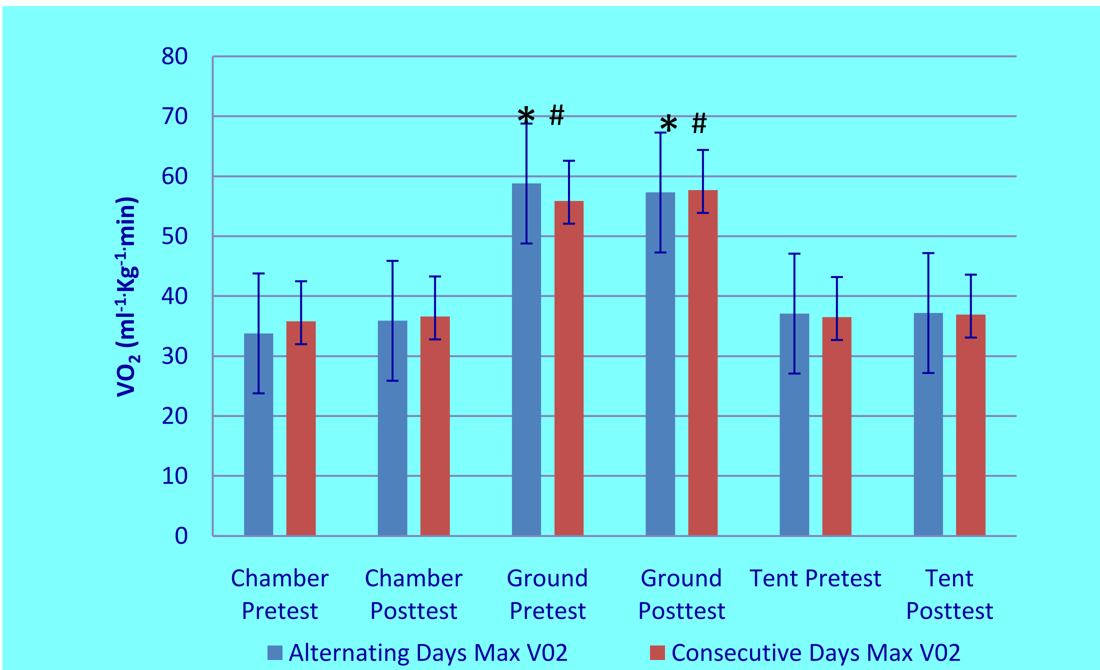


Figure 5. Aerobic Max VO_2 Test Results Between Environments

Bars indicate mean ± standard deviation. * P<0.001 between chamber and ground testing. # P<0.001 between chamber and tent testing.

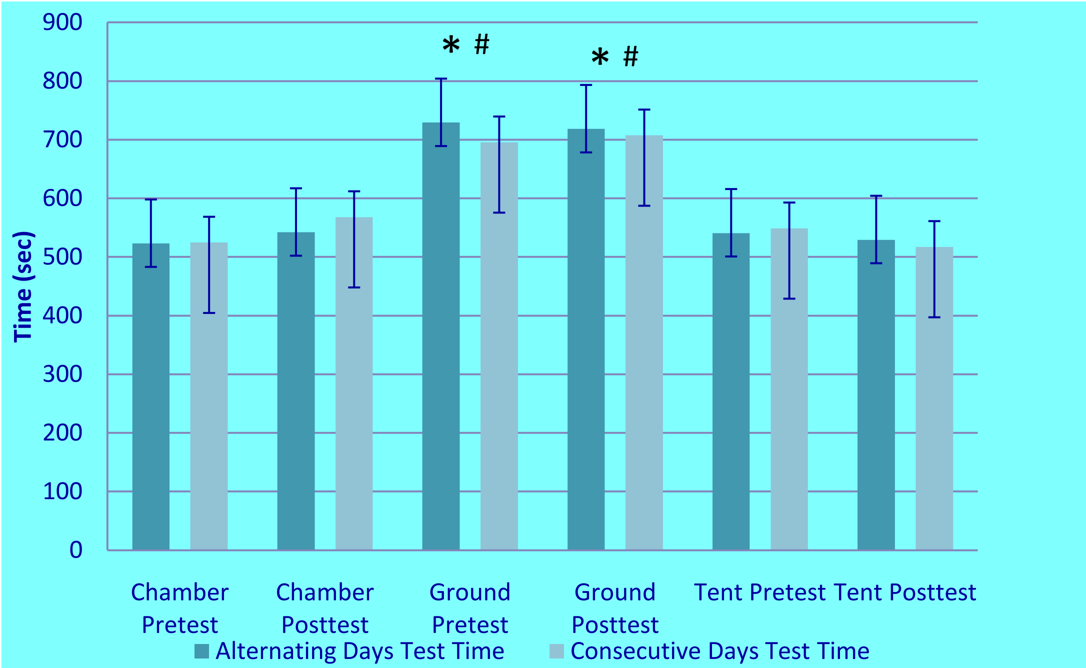


Figure 6. Max VO_2 Test Time Between Environments

Bars indicate mean ± standard deviation. * P<0.001 between chamber and ground testing. # P<0.001 between chamber and tent testing.

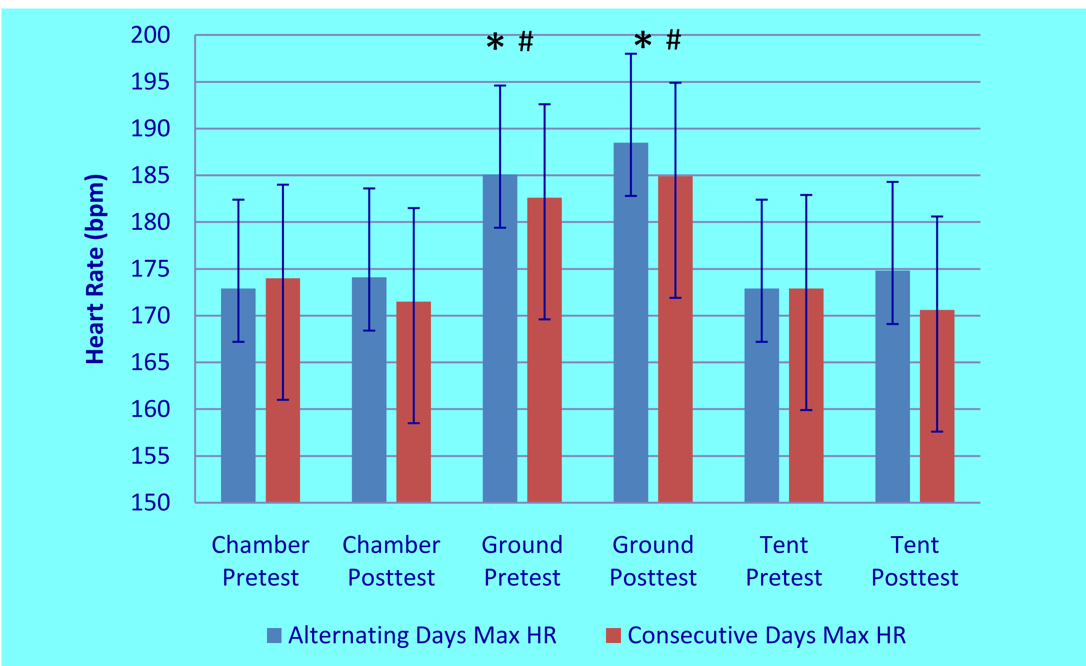


Figure 7. Max VO_2 Heart Rates Between Test Environments

Bars indicate mean ± standard deviation. * P<0.001 between chamber and ground testing. # P<0.001 between chamber and tent testing.

The results of the anaerobic endurance test are shown in Table 5. The results are again shown with C-IHE or A-IHE days of 1.5 hour hypoxic treatment. There were no differences between the and post-tests in any of the three environments (i.e., chamber, ground, or tent). There were also no differences between the type of IHE treatment the subjects received (A-IHE or C-IHE). There was a significant difference in total distance ran between the chamber and the ground (p = .04) and a trend was seen in total time ran between the chamber and the ground (p=.061) (see Figures 8 and 9). Maximal heart rates and peak lactate values did not change between environments.

Table 5. Anaerobic Endurance Test Results

		Chamber Pretest	Chamber Post-test	Ground Pretest	Ground Post-test	Tent Pretest	Tent Post-test
Alternating Days	Total Time (sec) ± Std Dev	52.0 ± 14.8	51.5 ± 12.6	55.6 ±24.9	59.3 ± 21.7	59.5 ± 16.2	51.2 ± 21.7
	Distance (yards) ± Std Dev	194.0 ± 55.8	189.5 ± 49.8	214.8 ± 99.7	229.8 ± 77.0	227.2 ± 62.8	196.0 ± 79.3
	Peak HR (bpm) ± Std Dev	174.0 ± 9.6	171.9 ± 12.9	177.6 ± 11.8	181.3 ± 16.0	174.5 ± 8.3	178.4 ± 13.1
	Lactate (mmol/L) ± Std Dev	12.4 ± 3.4	11.6 ± 1.3	12.7 ± 4.7	12.0 ± 3.6	12.8 ± 2.9	11.6 ± 3.8
Consecutive Days	Total Time (sec) ± Std Dev	43.8 ± 20.0	56.7 ± 20.6	70.8 ± 21	72.5 ± 21.6	58.0 ± 14.3	53.8 ± 16.7
	Distance (yards) ± Std Dev	170.8 ± 91.3	209.5 ± 78.1	268.7 ± 77.7	274.5 ± 85.5	218.3 ± 57.0	204.8 ± 66.4
	Peak HR (bpm) ± Std Dev	175.0 ± 8.1	172.2 ± 8.2	179.0 ± 10.0	180.2 ± 11.3	168.7 ± 9.0	175.0 ± 18.4
	Lactate (mmol/L) ± Std Dev	13.2 ± 1.5	11.5 ± 2.0	13.9 ± 3.9	12.4 ± 3.7	11.8 ± 3.9	12.5 ± 3.0

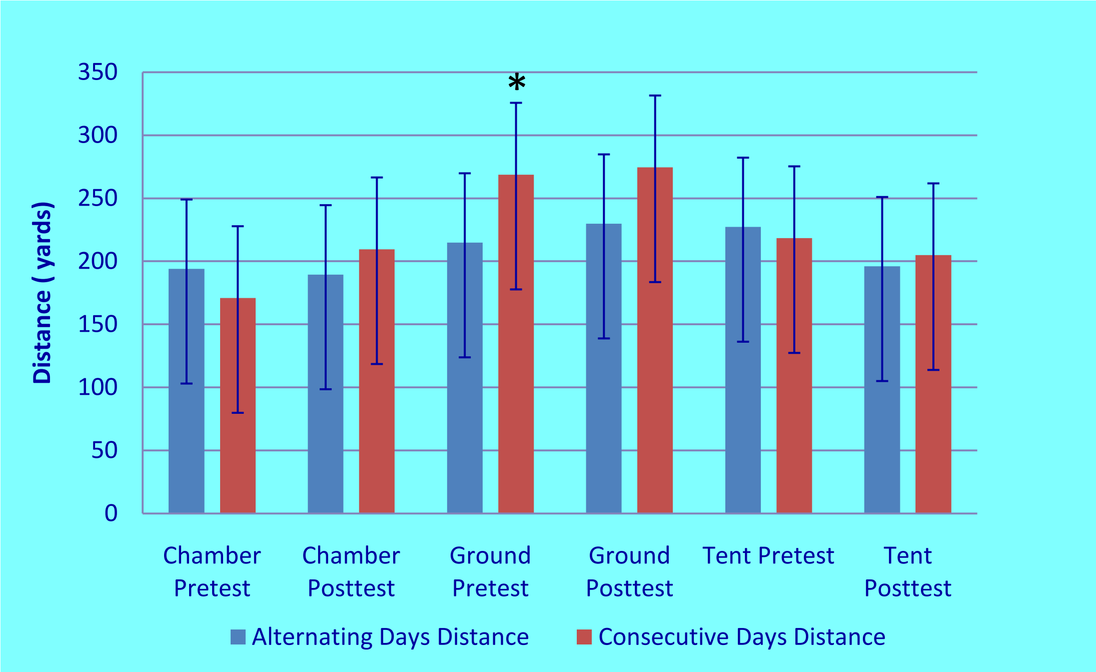


Figure 8. Distance during Anaerobic Endurance Test Between Test Environments

Bars indicate mean ± standard deviation. * p<0.05 between chamber and ground testing.

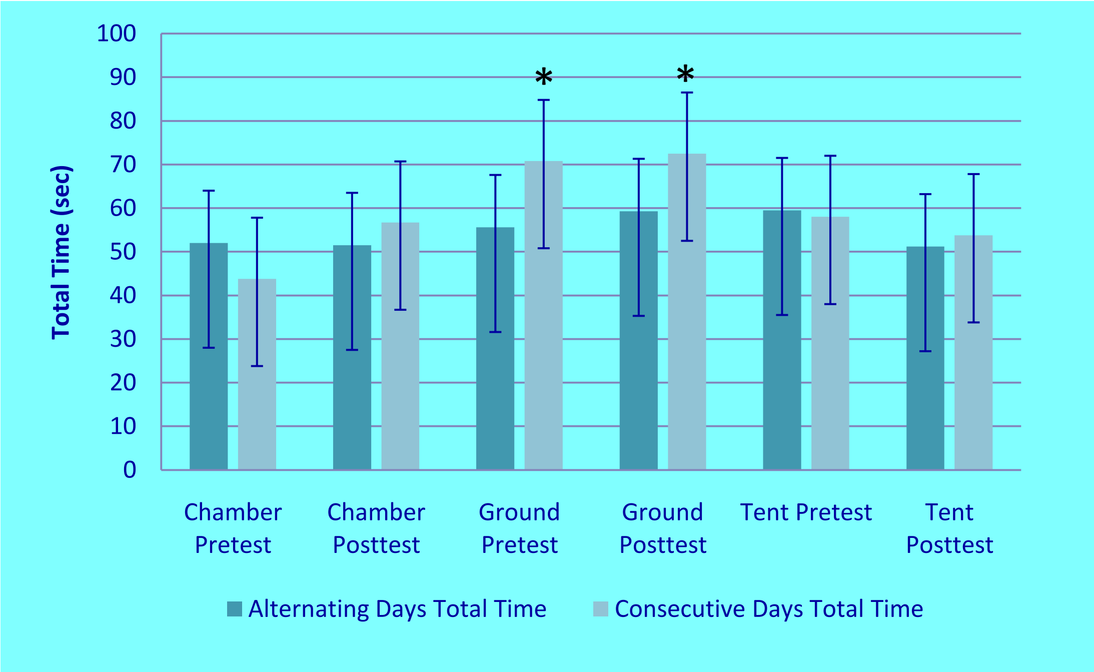


Figure 9. Anaerobic Endurance Test Times Between Test Environments

Bars indicate mean ± standard deviation. * p<0.05 between chamber and ground testing.

The results of SaO_2 measurements are shown in Table 6. The results are again shown with consecutive or alternating days of 1.5-hour hypoxic treatment. There were no differences between the and post-tests at any of the three environments (chamber, ground, or tent) or in the type of treatment the subjects received (alternating or consecutive). There were multiple differences seen in SaO_2 between environments (see Figures 10 through 15).

Table 6. Pulse Ox Results

		Chamber Pretest	Chamber Post-test	Ground Pretest	Ground Post-test	Tent Pretest	Tent Post-test
Alternating Days	**Initial ± Std Dev**	96.8 ± 0.8	95.5 ± 6.3	96.8 ± 1.6	97.4 ± 0.8	96.0 ± 3.4	97.1 ± 1.7
	VO_2 ± Std Dev	72.0 ± 2.9	72.6 ± 6.7	95.8 ± 1.3	97.1 ± 1.1	74.5 ± 6.1	77.1 ± 3.7
	Makoto ± Std Dev	75.0 ± 3.8	75.4 ± 6.4	94.8 ± 2.9	96.3 ± 2.0	78.5 ± 5.5	79.7 ± 5.3
	Force ± Std Dev	75.0 ± 1.9	74.3 ± 6.3	97.2 ± 0.8	97.0 ± 1.0	75.5 ± 4.9	77.6 ± 5.9
	Stroop ± Std Dev	77.6 ± 2.6	77.5 ± 6.7	95.9 ± 0.6	96.7 ± 0.6	83.4 ± 2.3	84.6 ± 1.3
	AMS ± Std Dev	73.5 ± 12.7	75.1 ± 9.5	96.4 ± 0.6	96.6 ± 0.9	84.0 ± 2.9	85.3 ± 1.9
Consecutive Days	**Initial ± Std Dev**	94.7 ± 6.1	96.8 ± 1.0	97.1 ± 0.7	97.0 ± 1.0	97.8 ± 0.8	97.4 ± 1.4
	VO_2 ± Std Dev	70.3 ± 6.2	71.7 ± 7.3	96.4 ± 1.9	95.4 ± 3.9	74.8 ± 9.3	77.3 ± 7.5
	Makoto ± Std Dev	74.3 ± 6.6	77.3 ± 4.5	95.9 ± 1.8	96.3 ± 1.0	78.7 ± 5.5	80.6 ± 4.7
	Force ± Std Dev	73.9 ± 5.6	76.7 ± 4.8	97.6 ± 1.4	95.0 ± 4.5	78.2 ± 6.4	76.7 ± 8.4
	Stroop ± Std Dev	80.5 ± 3.9	81.3 ± 2.7	96.7 ± 0.7	93.9 ± 7.4	84.1 ± 2.8	84.9 ± 3.0
	AMS ± Std Dev	71.3 ± 20.3	81.4 ± 3.6	97.1 ±.5	96.4 ±.7	83.9 ± 3.5	84.6 ± 2.7

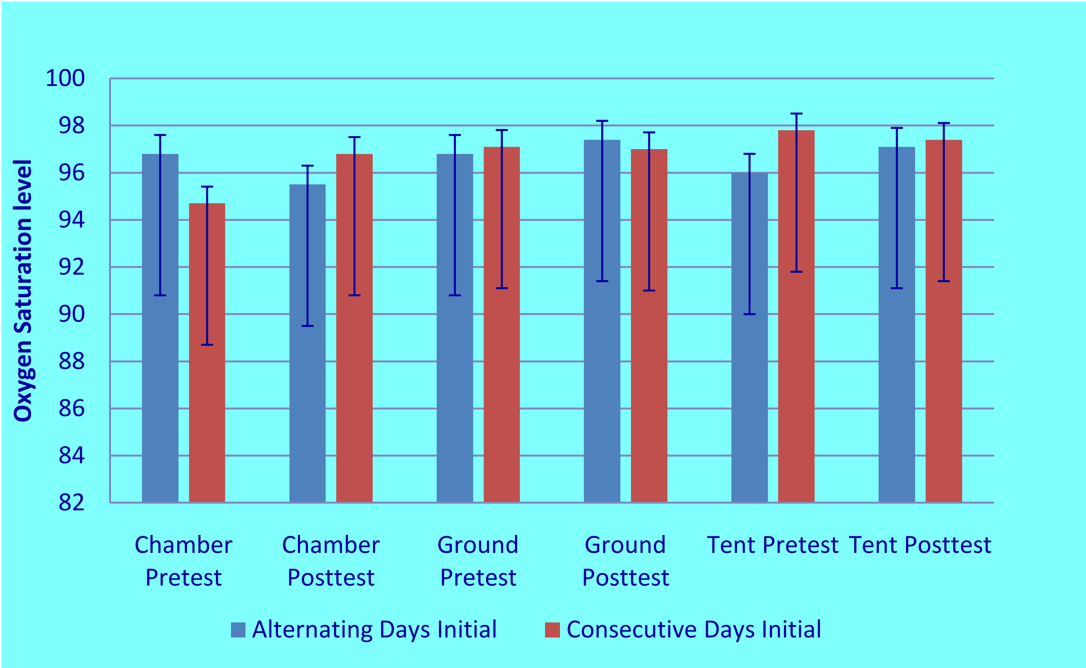


Figure 10. Initial Oxygen Saturation Levels Between Environments

Bars indicate mean ± standard deviation. No differences were seen between environments.

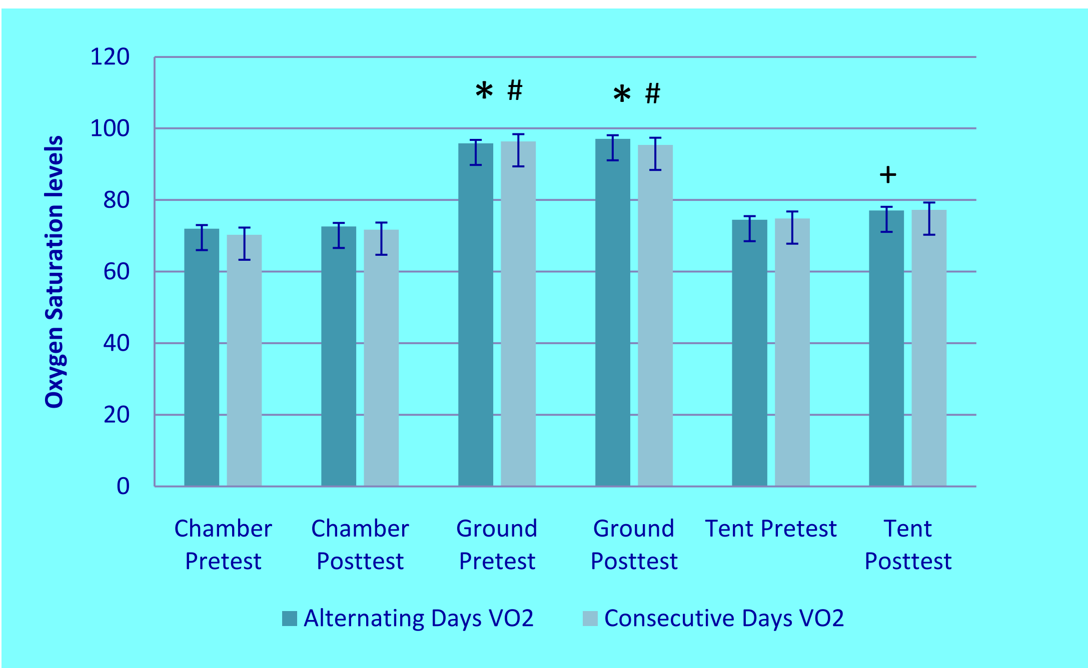


Figure 11. Oxygen Saturation Levels Between Environments Following Max VO_2 Test

Bars indicate mean ± standard deviation. * p<0.001 between chamber and ground testing. # p<0.001 between chamber and tent testing. + p<0.01 between chamber and tent testing.

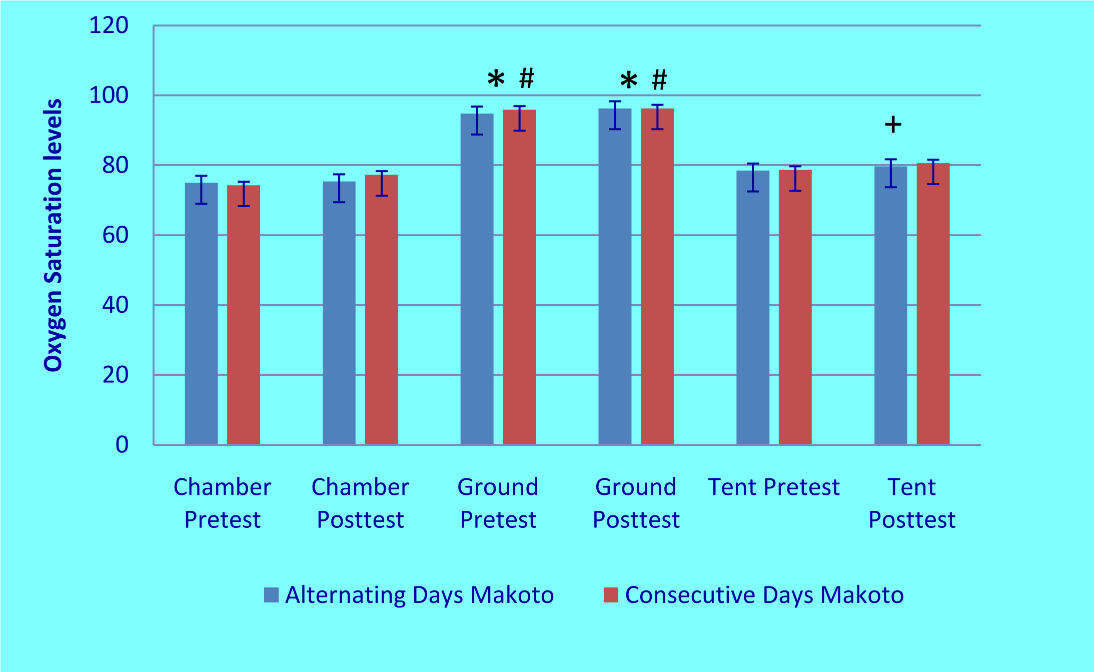


Figure 12. Oxygen Saturation Levels Between Environments Following Makoto Tests

Bars indicate mean ± standard deviation. * p<0.001 between chamber and ground testing. # p<0.001 between chamber and tent testing. + p<0.01 between chamber and tent testing.

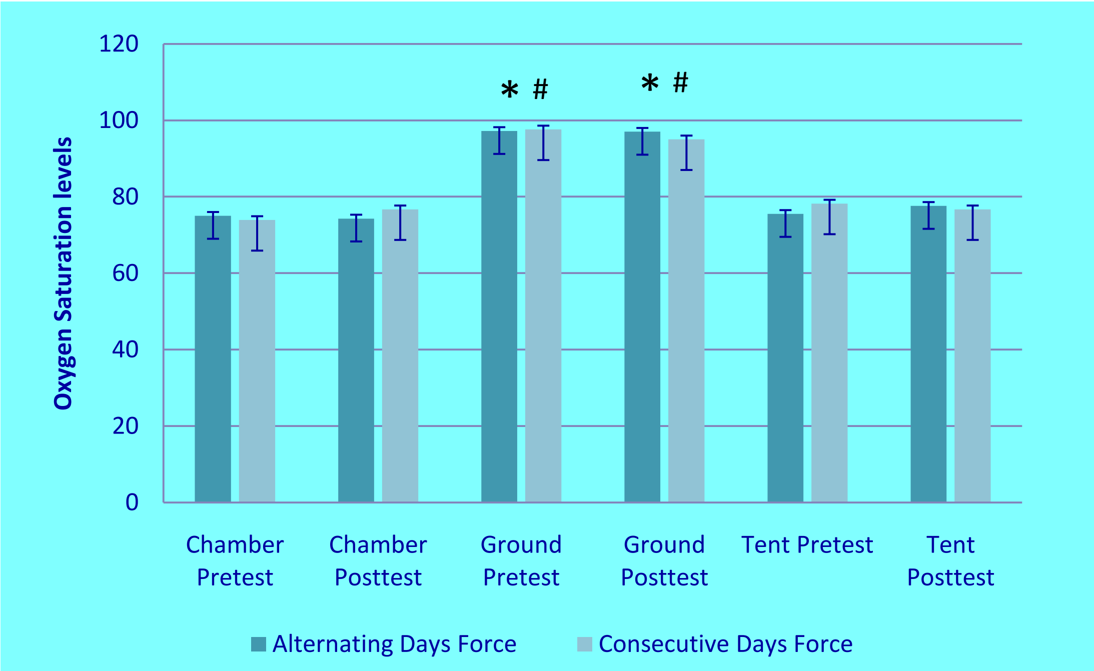


Figure 13. Oxygen Saturation Levels Between Environments Following Anaerobic Endurance Test on the Force

Bars indicate mean ± standard deviation. * p<0.001 between chamber and ground testing. # p<0.001 between chamber and tent testing.

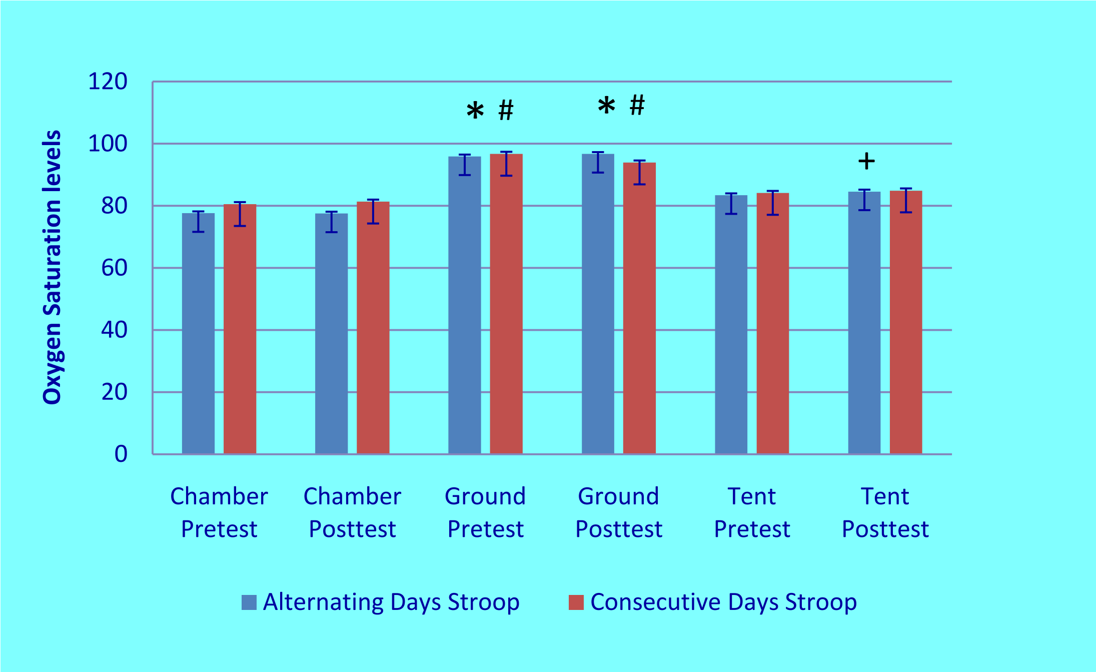


Figure 14. Oxygen Saturation Levels Between Environments Following Stroop Tests

Bars indicate mean ± standard deviation. * p<0.001 between chamber and ground testing. # p<0.001 between chamber and tent testing. + p<0.001 between chamber and tent testing.

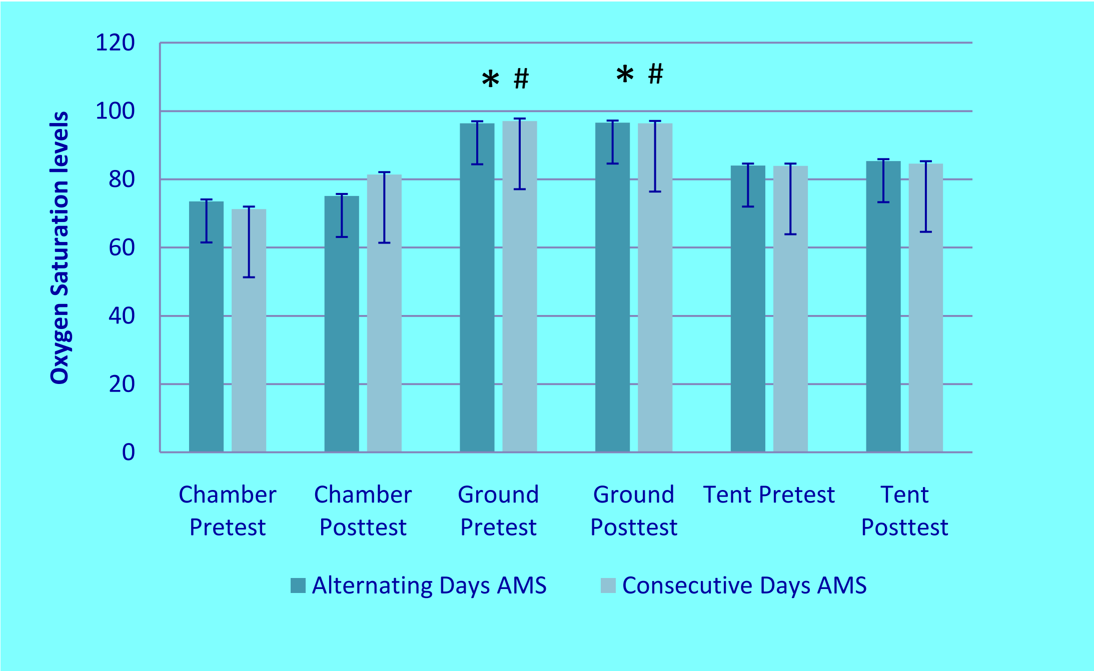


Figure 15. Oxygen Saturation Levels Between Environments Following AMS Tests

Bars indicate mean ± standard deviation. * p<0.001 between chamber and ground testing. # p<0.001 between chamber and tent testing. + p<0.001 between chamber and tent testing.

The results of the Makoto eye-hand speed and coordination tests are shown in Table 7. The results are shown for each treatment of consecutive or alternating days for both modes of testing (proactive and reactive). There were no differences between the type of treatment the subjects received although a definite trend was seen with lower accuracy in the reactive mode (p=.075) during the consecutive day treatment. There were significant differences in the reactive test results in the tent compared to the chamber (p=.000) and ground testing (p=.013). These differences can be seen in Figure 16.

Table 7. Eye-Hand Coordination (MAKOTO) Results

	Chamber Pretest	Chamber Post-test	Ground Pretest	Ground Post-test	Tent Pretest	Tent Post-test
Alternating Days Proactive ± SD	.54 ± .06	.54 ± .04	.54 ± .06	.55 ± .06	.58 ± .09	.56 ± .07
Alternating Days Reactive ± SD	86% ± 17%	78% ± 19%	71% ± 17%	68% ± 18%	53% ± 10%	56% ± 15%
Consecutive Days Proactive ± SD	.52 ± .03	.55 ± .06	.55 ± .05	.56 ± .04	.57 ± .06	.55 ± .06
Consecutive Days Reactive ± SD	64%± 16%	70% ± 19%	68% ± 21%	61% ± 11%	55% ± 11%	56% ± 13%

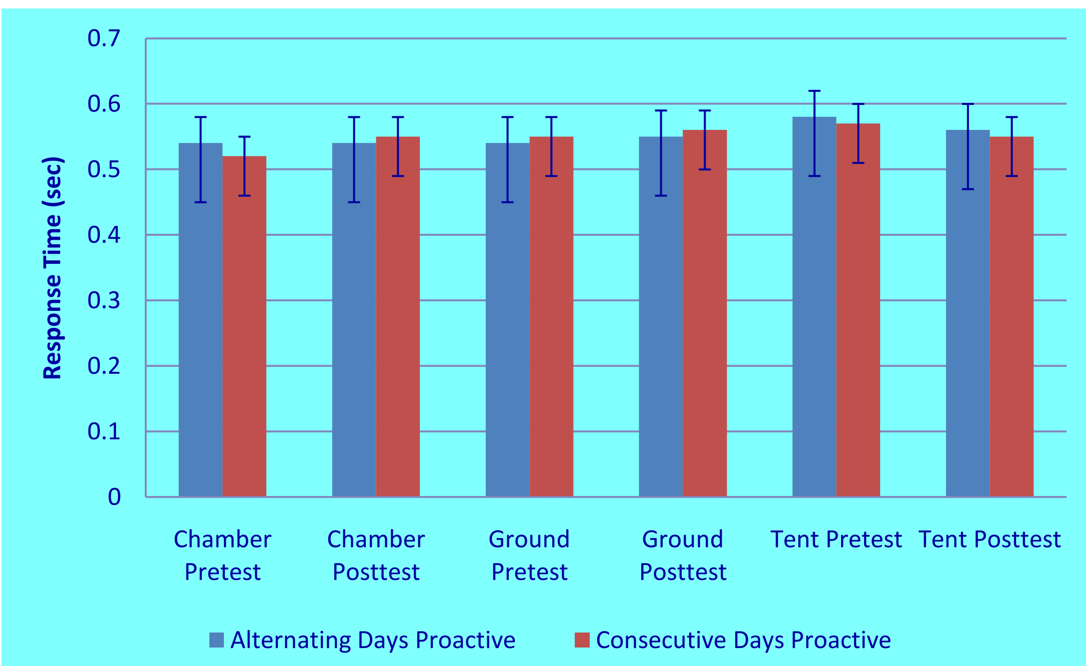


Figure 16. Makoto Proactive Reaction Times Between Environments

Bars indicate mean ± standard deviation. No differences were seen between environments.

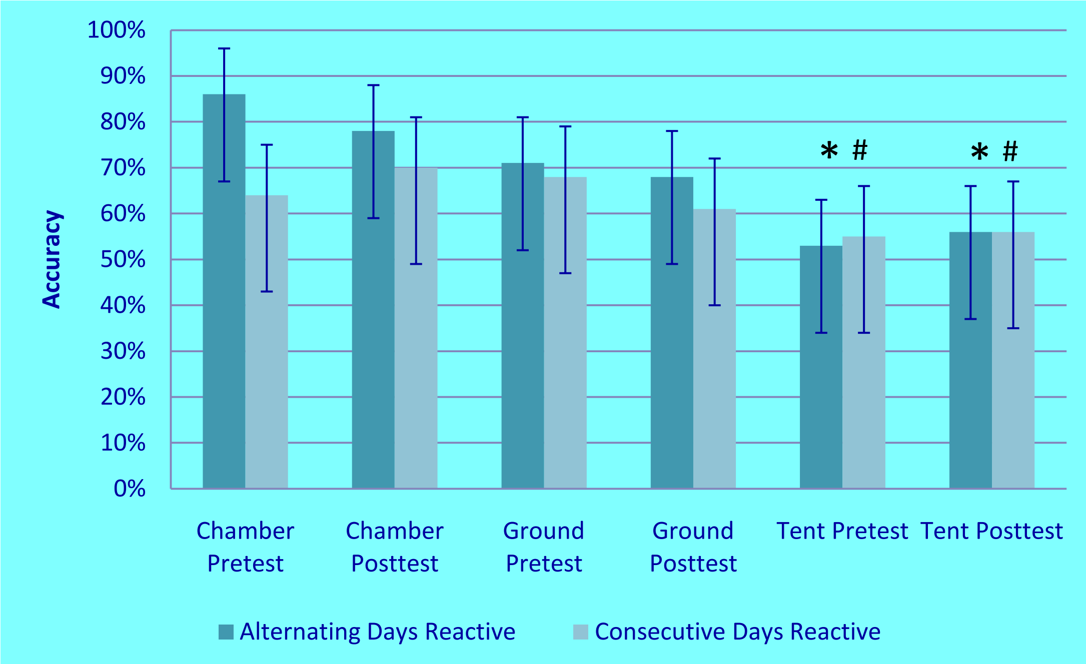


Figure 17. Makoto Reactive Percentage Hits Times Between Environments

Bars indicate mean ± standard deviation. * p<0.001 between chamber and tent testing. # p<0.05 between ground and tent testing.

The results of the Stroop test are shown with consecutive or alternating days of 1.5 hour hypoxic treatment in Table 8. Stroop 1 was taken at the start of each testing session. Stroop 2 and 3 were taken two and ten minutes after the max VO_2 test respectively. Stroop 4 and 5 were taken following the anaerobic endurance test at two and ten minutes. There were no significant differences between and post-tests at any of the environments or between alternative and consecutive treatments. The significant differences for Stroop 2 (p=.024) and Stroop 4 (p=.018) between the chamber and ground environments can be seen in Figures 18 and 19. In both cases, Stroop 2 (p=.055) and Stroop 4 (p=.073), there were trends seen between the chamber and tent.

Table 8. Stroop Response Time Results

	Consecutive IHE Days						Alternating IHE Days					
	Chamber		Ground		Tent		Chamber		Ground		Tent	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
S1 words/color ±StDev	28.17 ±4.61	26.07 ±4.26	25.98 ±3.75	26.06 ±6.35	24.63 ±4.20	25.70 ±5.19	25.99 ±4.86	29.05 ±9.38	24.73 ±7.42	25.85 ±6.86	25.77 ±8.48	23.50 ±5.68
S2 Words/Color ±StDev	28.88 ±4.38	26.11 ±3.23	24.85 ±3.52	23.34 ±3.98	26.16 ±3.18	23.45 ±3.18	27.54 ±8.05	28.3 ±7.32	25.51 ±7.15	23.66 ±6.36	25.13 ±4.75	24.20 ±6.38
S3 Words/Color ±StDev	30.04 ±4.89	25.67 ±3.82	25.75 ±4.05	23.32 ±3.73	26.08 ±3.91	25.05 ±3.98	25.98 ±4.53	27.18 ±6.17	26.74 ±6.76	25.66 ±6.55	25.50 ±5.99	24.38 ±5.85
S4 Words/Color ±StDev	29.44 ±5.25	27.39 ±4.70	25.42 ±4.27	22.95 ±6.39	23.84 ±2.50	25.18 ±4.59	27.88 ±9.09	28.55 ±6.51	24.31 ±8.76	24.01 ±6.41	26.82 ±7.18	24.24 ±6.66
S5 Words/Color ±StDev	29.08 ±4.32	27.10 ±6.14	25.57 ±3.58	22.26 ±4.34	24.97 ±3.26	26.09 ±3.38	27.13 ±6.71	26.59 ±6.71	26.38 ±4.63	24.69 ±8.15	26.09 ±6.38	24.36 ±6.40

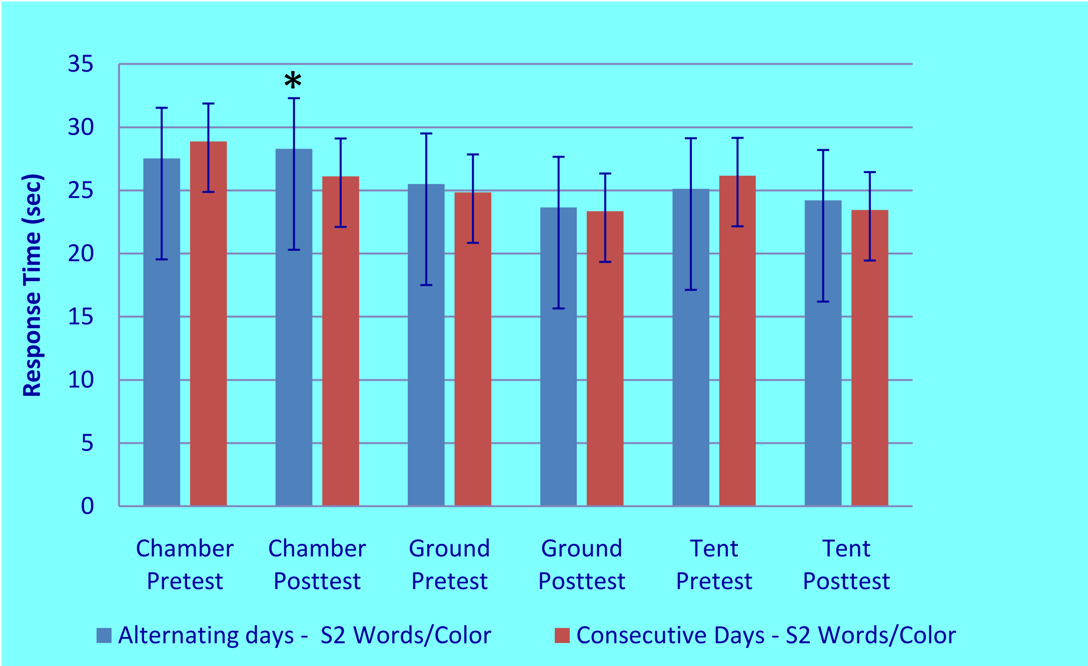


Figure 18. Two Minute Post Max VO_2 (S2) Stroop Test Between Environments

Bars indicate mean ± standard deviation. * p<0.05 between chamber and ground testing.

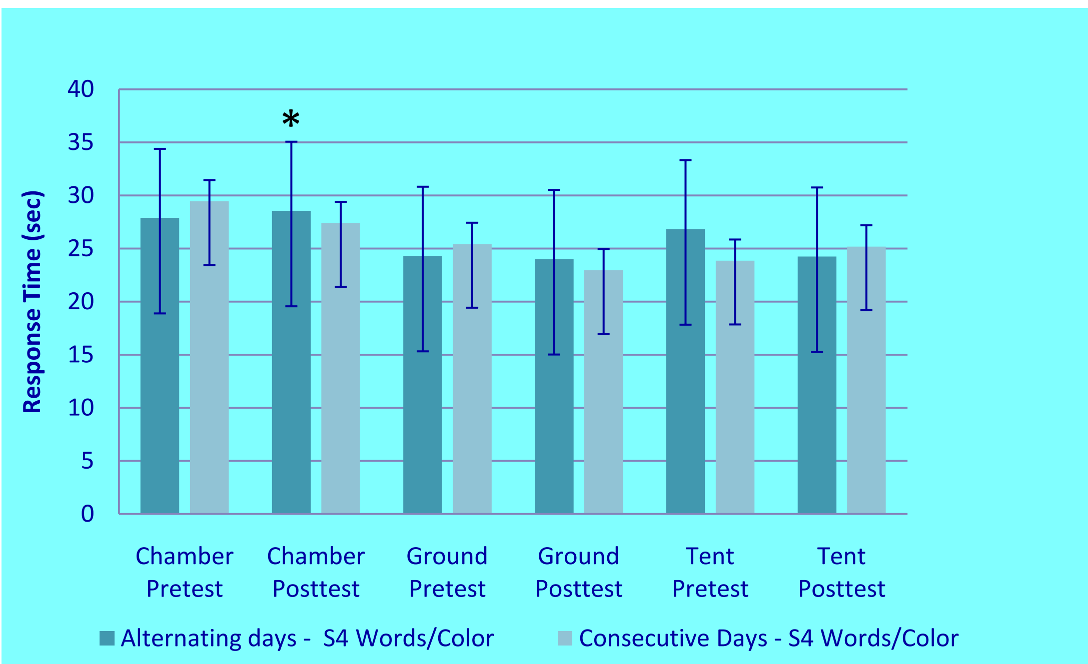


Figure 19. Two Minute Post Anaerobic Endurance (S4) Stroop Test Between Environments

Bars indicate mean ± standard deviation. * p<0.05 between chamber and ground testing.

Table 9 shows the subjects' accuracy in correctly answering during the Stroop test. The alternating IHE treatment showed a slightly higher accuracy in which subjects made fewer mistakes than during the consecutive IHE treatment, although it was a nonsignificant difference. There were no significant differences between pre- and post-tests nor were there significant differences between alternative and consecutive treatment in the Stroop accuracy. A significant difference (p=.023) for the two-minute post-VO_2 max Stroop (S2) test was seen between the chamber and ground tests.

Table 9. Stroop Test Accuracy Results

	Consecutive IHE Days						Alternating IHE Days					
	Chamber		Ground		Tent		Chamber		Ground		Tent	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
S1 words/color ±StDev	86% ±.38	43% ±.79	100% 0	86% ±.38	100% 0	71% ±.49	100% 0	86% ±.38	86% ±.38	83% ±.41	86% ±.38	100% 0
S2 Words/Color ±StDev	71% ±.49	57% ±.53	100% 0	100% 0	71% ±.49	100% 0	67% ±.52	100% 0	86% ±.38	100% 0	86% ±.38	83% ±.41
S3 Words/Color ±StDev	57% ±.49	57% ±.79	57% ±.79	86% ±.38	71% ±.76	86% ±.38	86% ±.38	100% 0	86% ±.38	100% 0	86% ±.38	83% ±.41
S4 Words/Color ±StDev	86% ±.38	100% 0	71% ±.76	100% 0	86% ±.38	57% ±.79	71% ±.49	86% ±.38	100% 0	100% 0	71% ±.49	83% ±.41
S5 Words/Color ±StDev	57% ±.79	86% ±.38	100% 0	100% 0	100% 0	86% ±.38	100% 0	71% ±.49	86% ±.38	100% 0	100% 0	83% ± .41

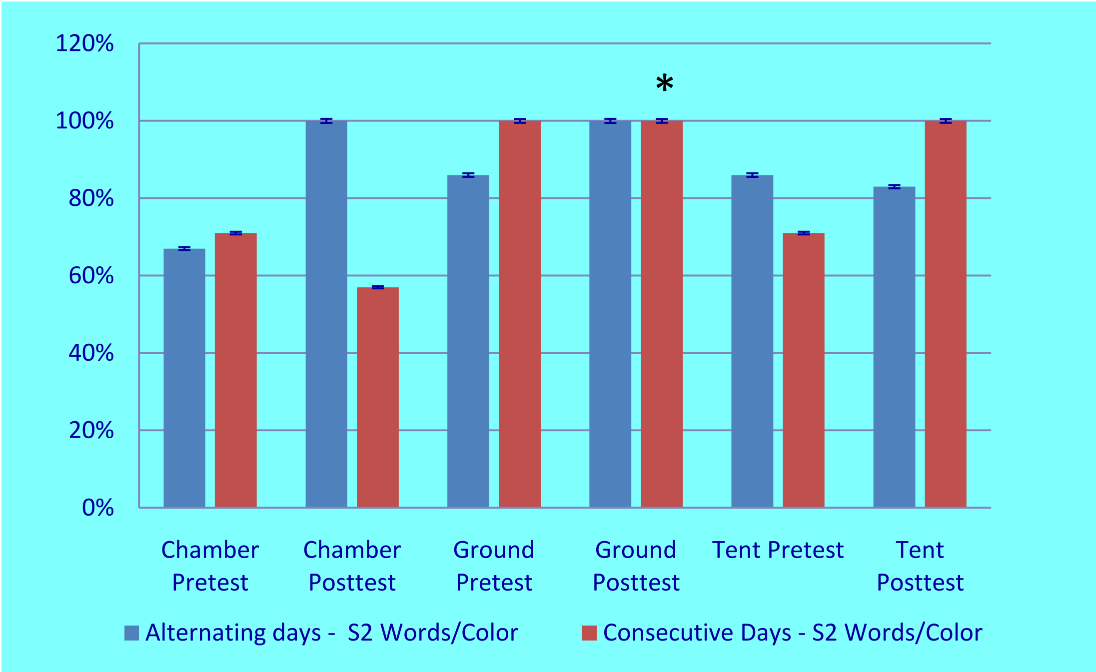


Figure 20. Two-Minute Post-VO_2 Max (S2) Stroop Test Between Environments

Bars indicate mean ± standard deviation. * p<0.05 between chamber and ground testing.

Table 10 shows the results of the subject's Acute Mountain Sickness and Environmental Symptoms Questionnaires results. Subjects completed the questionnaires at the initial start of the testing session, after their max VO_2, and after the anaerobic endurance test. There were no significant differences between pretests and post-tests for each of the three environments (chamber, ground, and tent). There was also no significant difference between the type of treatments the subjects received.

Table 10. AMS and ESQ Results

	Alternating IHE Days						Consecutive IHE Days					
	Chamber		Ground		Tent		Chamber		Ground		Tent	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
AMS 1 ±StDev	.5 ±.84	.14 ±.38	.29 ±.76	0 0	0 0	0 0	.14 ±.38	.14 ±.38	0 0	0 0	0 0	.14 ±.38
AMS 2 ±StDev	1.29 ±1.38	1.14 ±.90	.43 ±.53	.5 ±.84	.71 ±.95	.5 ±8.4	.86 ±1.46	.86 ±.69	.43 ±.53	.57 ±.79	.57 ±.53	.88 ±.90
AMS 3 ±StDev	1 ±1.29	.57 ±.79	.71 ±.76	.8 ±1.30	1 ±1.29	.83 ±1.17	1 ±1.15	1 ±.82	.43 ±.79	.67 ±.82	.33 ±.52	.86 ±.90
ESQ 1 ±StDev	8.33 ±7.17	7.71 ±5.59	7.71 ±5.25	7.17 ±5.60	8.17 ±6.24	5.83 ±5.08	7.43 ±5.56	7.71 ±5.74	6.29 ±6.02	8.29 ±5.47	7 ±5.51	8.29 ±6.50
ESQ 2 ±StDev	13.71 ±7.11	12.71 ±7.74	11.57 ±6.55	12.67 ±9.44	11.43 ±7.68	11.17 ±6.24	15 ±9.76	12.29 ±6.32	9.29 ±6.52	11 ±6.30	9.86 ±6.69	10 ±6.32
ESQ 3 ±StDev	16 ±13.10	13.43 ±8.99	12 ±7.46	11.67 ±7.50	13.43 ±9.18	12.17 ±7.57	12 ±7.70	14.71 ±9.38	9.57 ±5.68	11.86 ±7.34	10.43 ±6.48	12.71 ±7.20

DISCUSSION

The primary objective of this study was to determine if alternating days of intermittent normobaric hypoxic exposures (IHE) for a previously unacclimatized sea-level resident (SLR) would work as a training strategy to minimize physical and cognitive impairments and possibly reduce acute mountain sickness (AMS) incidence in battlefield airmen during deployment. A secondary objective was to compare the physical and cognitive performance results between hypobaric hypoxic and normobaric hypoxic conditions.

The results reveal that there were no differences in physical performance, cognitive performance, or the incidence of acute mountain sickness in subjects when exposed to moderate altitude following five days of alternating or five days of consecutive intermittent hypoxic exposures. While there were no differences between the two IHE strategies, we also found that the current recommended procedures for using IHE for five consecutive days at 4,000 m (13,200 ft) for 1.5 hours during the week prior to altitude deployments (Muza, 2007) may be insufficient to help maintain physical or cognitive performance at altitude. Beidleman et al. (2009b) found that 2 hours 50 minutes of IHE with exercise training for one week did not improve endurance performance at moderate altitude. That was about double the time our subjects were exposed to IHE each day.

Another possible reason that we did not detect any significant differences between the two treatments or between pre- and post- IHE for either treatment may be due to the low number of test subjects. Our initial goal was to test 20 subjects, which would have given the study a power of 93%, but due to a delayed start and losing personnel due to our base closing, we failed to recruit potential subjects. With this reduced power, we saw a large amount of variability and unclear results in many of the performance measures.

The gains in aerobic performance ($VO_{2\ Peak}$) at moderate altitude were only 6% following A-IHE and 2% following C-IHE. These gains occurred with only a 1% and 2% increase in SaO_2 for A-IHE and C-IHE, respectively. These aerobic gains are minimal considering that our subjects aerobic performance decreased by 38% when exposed to hypobaric hypoxia in the altitude chamber. Another conflicting result is while VO_2 only increased 2% following C-IHE, the treadmill test time increased 8%.

We saw differing results with the anaerobic endurance and Makoto tests compared to the aerobic performance. The anaerobic test distance achieved decreased 2% following A-IHE, but increased 18% following C-IHE. This non-significant 18% gain made up half of the 36% loss that occurred when exposed to hypobaric hypoxia. These results are comparable to a recent study that found a 3% increase in mean power following 90 minutes of intermittent hypoxic training for 10 days (Hamlin, Marshall, Hellemans, Ainslie, & Anglem, 2010). Both Makoto tests, proactive (5%) and reactive (9%), increased following the C-IHE, while the A-IHE treatment resulted in no change for the proactive test and 10% decreased performance during the reactive test. From these unclear results, we can't make any firm conclusions on why certain changes occurred.

Significant differences in Stroop test response time and accuracy were seen between the chamber and ground environmental tests following the VO_2 max tests. It is no surprise that a difference in response time and accuracy would be seen in post physical fitness Stroop tests. Hogervorst et al. (1996) found that exercise has a positive effect on performance speed in simple tasks. They found that the response time for the Color-Word Interference of the Stroop test was decreased, meaning they got faster, following endurance exercise. In their study, the subjectively experienced effort was not increased and no more errors were made with the higher speed of performance. We also observed subjects to have significant differences or trends towards a decrease in response time and an increase in accuracy after the physical performance test. Future studies, with a higher number of subjects, could see how an individual exercising longer in these environmental conditions may have an effect on their cognitive performance. With only a small number of subjects, it is hard to determine how significant of an effect the physical performance in these environments had on the subjects' cognition.

The AMS and Environmental Symptoms Questionnaires were administered three times throughout each testing session. Subjects had the same scores for the AMS in the chamber environment at pretest and post-test when doing consecutive IHE treatments. During alternating days of IHE treatments, the chamber post-test scores continued to be lower (indicating fewer symptoms) than the chamber pretest throughout the testing session. Further research could conclude that alternate IHE treatment may help to decrease acute mountain sickness. Beidleman et al. (2009a) recently showed that six days of staging at 2200 m reduced the incidence and severity of AMS during rapid ascent to 4300 m. In the Environmental Symptoms Questionnaire, subjects tended to show fewer symptoms in the consecutive IHE treatments than during the alternating IHE treatments. However, in both treatments and in all three types of environments, subjects' symptoms continued to increase throughout the testing sessions. The 1.5 hours of IHE treatment or testing was probably not a long enough duration for the subjects to fully develop AMS symptoms.

We did find some interesting results when we compared tests between hypobaric hypoxia in the chamber and normobaric hypoxia in the tent. The subjects achieved a 4% higher VO_2 max in the tent compared to the chamber. This occurred with the subjects achieving the same maximal heart rates and treadmill test times. This corresponded very closely with the oxygen saturation differences of 6% seen between the two environments (with the tent tests having the higher oxygen saturations).

We also saw 9% longer runs in the tent during the anaerobic endurance test. The subjects were able to run this longer distance while achieving the same heart rate and blood lactate values. The oxygen saturation differences were only 3% higher in the tent compared to the chamber during these runs.

The results of the Makoto eye-hand speed were contradictory to the max VO_2 and anaerobic endurance tests. The subjects did 36% better for the reactive tests and 5% higher during the proactive tests in the altitude chamber. One explanation may be the position of the tower in the tent. It was located behind the force treadmill and was in a more confined space compared to the chamber tower, which may have hindered the subjects' performance.

CONCLUSIONS

Five alternating days of intermittent hypoxic exposures for 1.5 hours per day are as effective (or ineffective) as five consecutive days of IHE at mitigating the negative effects of moderate altitude on physical and cognitive performance. There were no differences in physical performance, cognitive performance, or the incidence of acute mountain sickness between the IHE treatments in subjects exposed to a moderate altitude.

Neither IHE treatment, alternating days or consecutive days, were effective in increasing physical or cognitive performance at moderate altitudes following five days of exposures.

There are different physiological responses in subjects exposed to hypobaric hypoxic compared to normobaric hypoxic. Further research is needed in this area to determine why the body responses differently to the two types of hypoxic environments.

Our recommendation is for further research in this area with as increased number of hypoxic training sessions of longer durations.

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